

One Biology, One Science
A Vision for 21st Century Biology

James P. Collins

Assistant Director for Biological Sciences

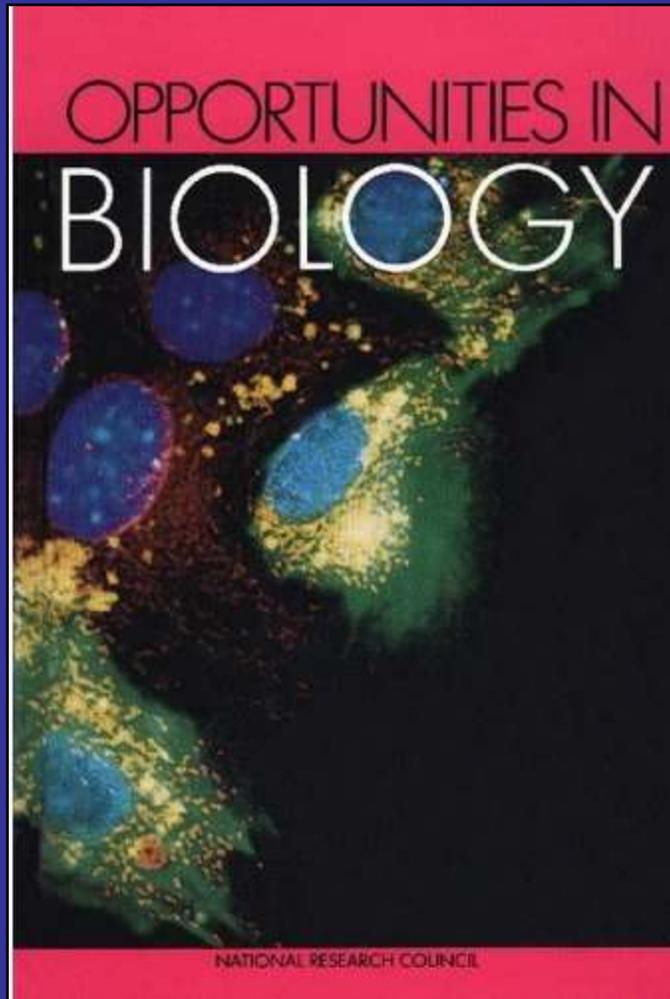
National Science Foundation



Advisory Committee for Biological Sciences

April 29, 2009

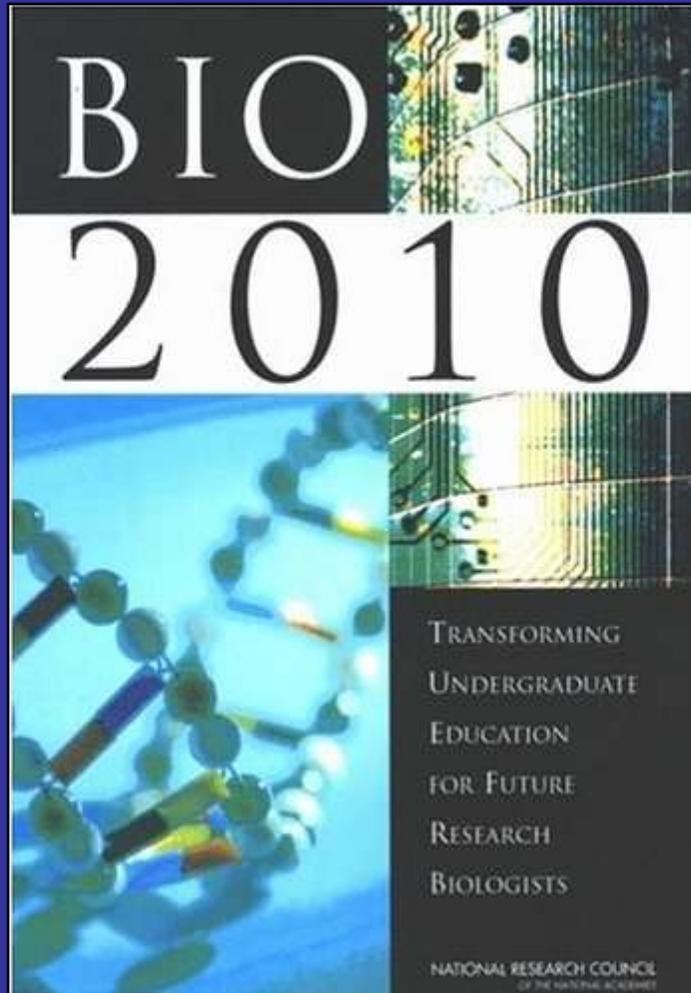
Major NRC Biology Reports



National Research Council 1989

“...biological research has been transformed from a collection of single-discipline endeavors to an interactive science in which traditional disciplines are being bridged.”

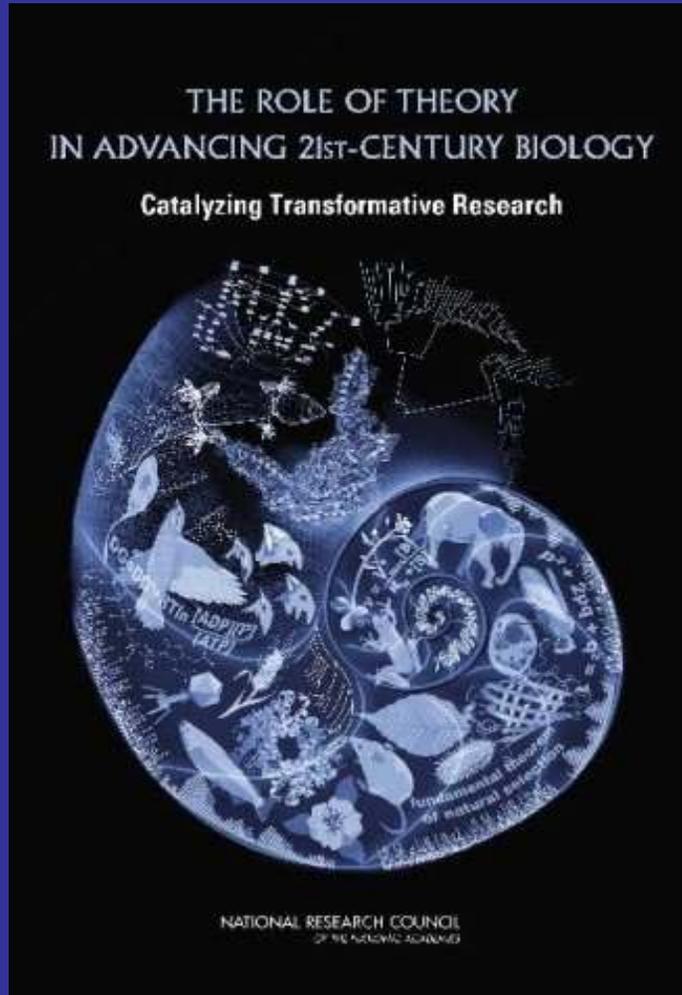
Major NRC Biology Reports



National Research Council 2003

“Connections between biology and other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature.”

Major NRC Biology Reports



National Research Council 2008

“Tying together the results of research in many diverse areas of biology requires a robust theoretical and conceptual framework...”

Major NRC Biology Reports

**NRC 21st Century
Biology Report**

2009

Arc of Biology

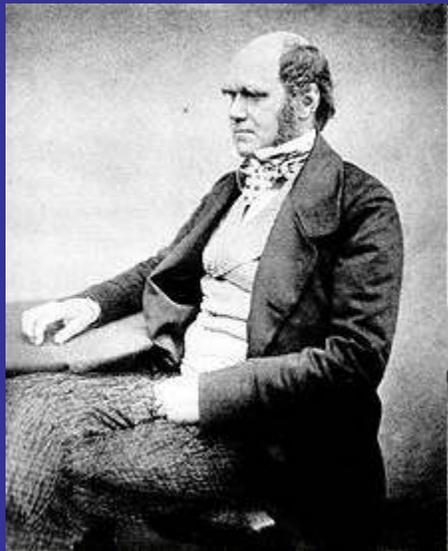
Life in Transition

Life Sciences in Transition

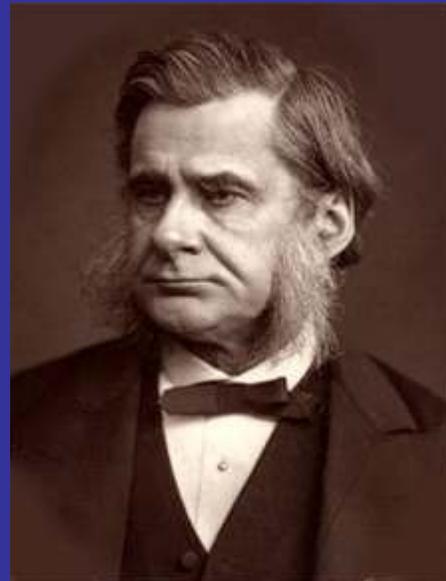
**Managing the Life Sciences
in Transition**

The Arc of Biology: 19th & 20th Centuries

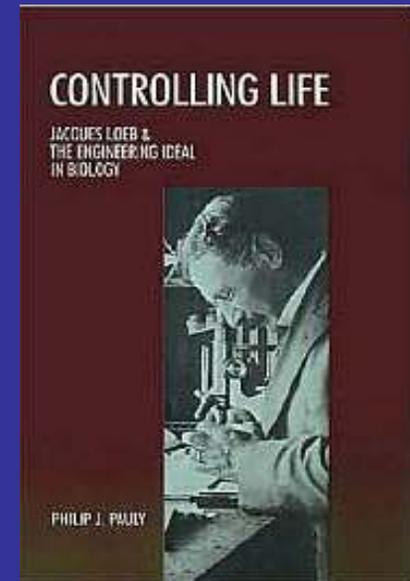
In the early 20th century biology emerged from natural history and physiology around the question: What is life?



Charles Darwin



T.H. Huxley



Jacques Loeb

Biologist Jacques Loeb (1859-1924) helped to shape modern biological research through his emphasis on reductionism, experiments, and the engineering ideal.

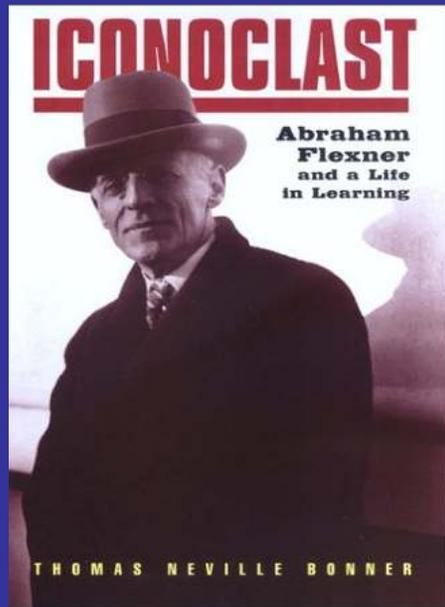
The Arc of Biology: What is Life?

Theoretical Constructs in Biology

- All living things are made from cells, the chemical factories of life: ***CELL BIOLOGY***
- All life is based on the same genetic code organized as DNA or RNA: ***GENETICS***
- All forms of life evolved by natural selection or genetic drift: ***EVOLUTION***
- All life is connected to form ecosystems: ***ECOLOGY***

The Arc of Biology: *Controlling Life*

20th century life sciences progressed around the goal of controlling living systems especially with respect of improving human health and agriculture.



Flexner Report (1910)

- Antiseptic Surgery
- Vaccination
- Public Sanitation
- Antibiotics
- Pesticides

The Arc of Biology:

Understanding and Controlling Life...

RNA Interference (RNAi) - An ancient evolutionary mechanism for silencing gene expression



Addition of
purple gene
copies



An innate and adaptive response that protects a cell from foreign genes by targeting invading gene messenger RNAs

The Arc of Biology: ...*To Improve the Quality of Life*

Practical application of RNAi in agricultural and medical biotechnology



Resistance to papaya virus



Therapeutic *RNAi*
macular degeneration

2006 Nobel Prize in Physiology and Medicine
to Fire and Mello

Pasteur's Quadrant

Consideration of Use

NO

YES

Donald E. Stokes
Brookings Institute

Pure Basic Research (Bohr)	Use-inspired Basic Research (Pasteur)
Exploration & Description (Peterson's Field Guides)	Pure Applied Research (Edison)

Environment
Energy

YES

Quest for
Fundamental
Understanding

NO

Pure basic and use-inspired basic research
are consistent with NSF core values and
evolving practice

unknown

RISK

known

Research to anticipate and reduce the impact of "surprises"

Precautionary actions to reduce potential risks

Actions to reduce known risks

Use-Inspired Research

Informs Policy Actions

certain

uncertain

IMPACT

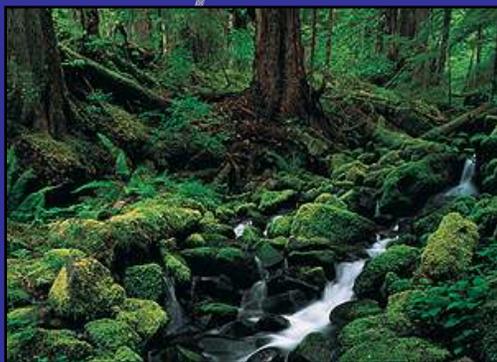
Based on: *Late Lessons from Early Warnings*, European Environment Agency 2001

The Arc of Biology into the 21st Century

Confronting the Question: What is Life?



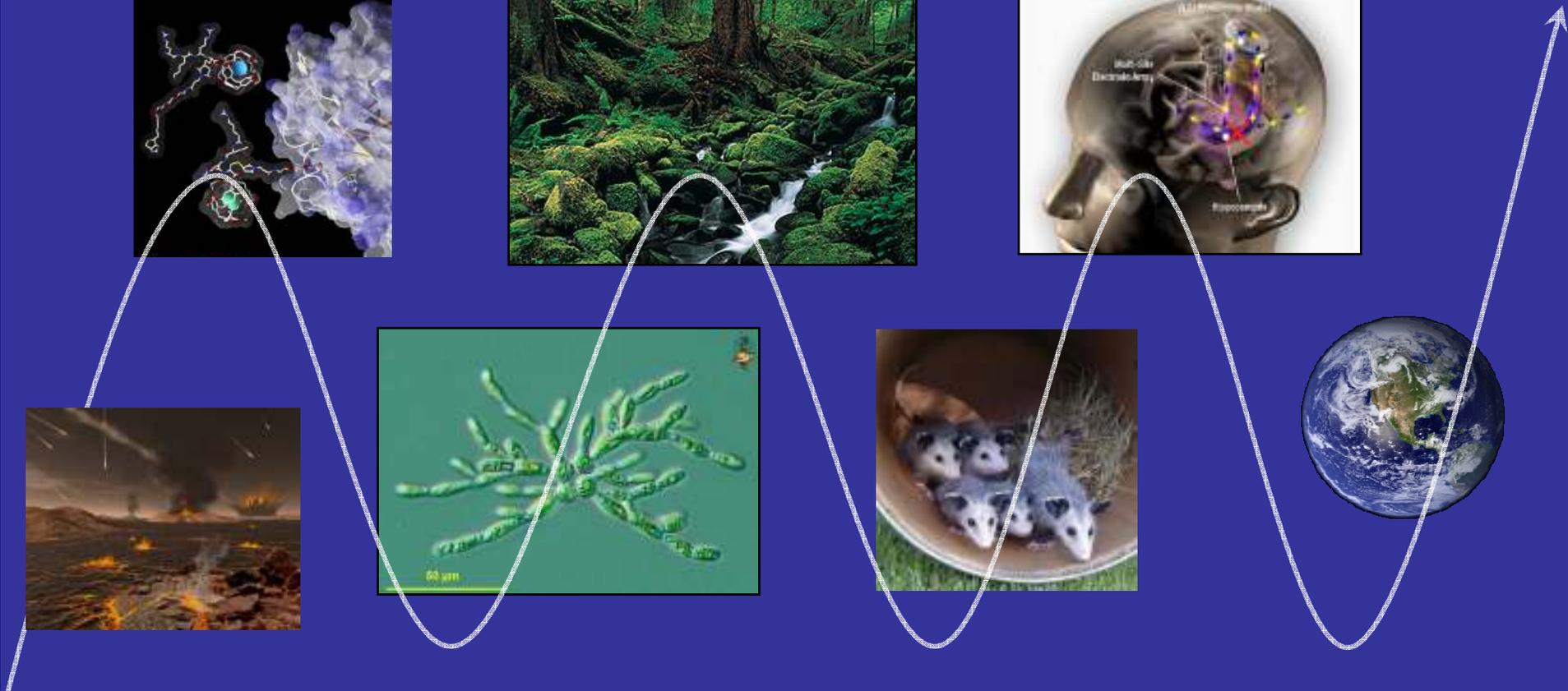
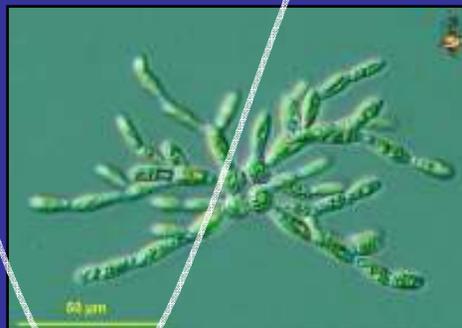
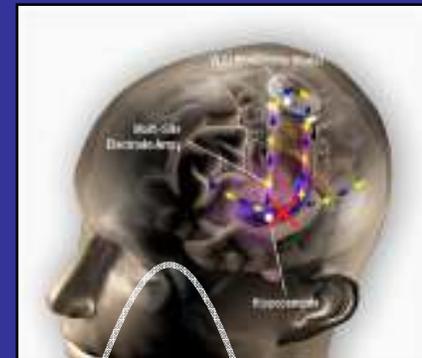
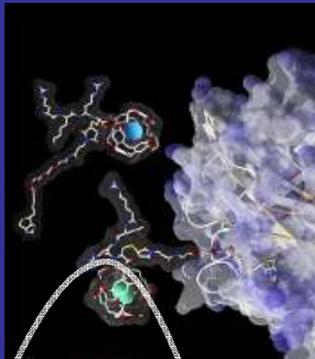
A vision for our planet's future based on a comprehensive understanding of the living world across scales of size, time, and place.



21st Century Biology must deal with the consequences of human technological achievements.

Life in Transition

Vision: Inspiring research and education at the frontiers of the life sciences



Life in Transition



Anoxic
World



Photosynthesis



Life on Land



O₂ Rich World

- ORIGINS
- ENERGY
- ADAPTATION

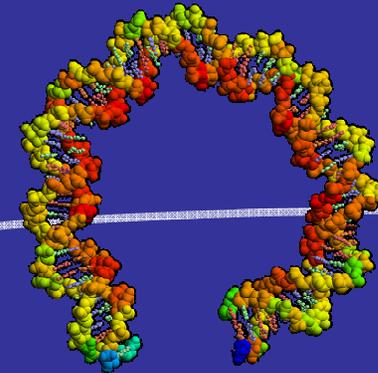
“Life Put Earth Under
New Management”

Origins: *How, where, and when did life on earth begin?*



Open system chemistry

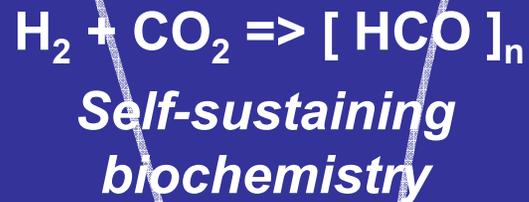
Self-replication



DNA World



RNA World



How did the biological complexity of life emerge from pre-biotic chemistry and geochemistry?

Self-contained – The Cell

Self-sustaining - Energy

Self-replicating – RNA, DNA

Evolving - Biodiversity



Basic elements

Systems & Synthetic Biology:

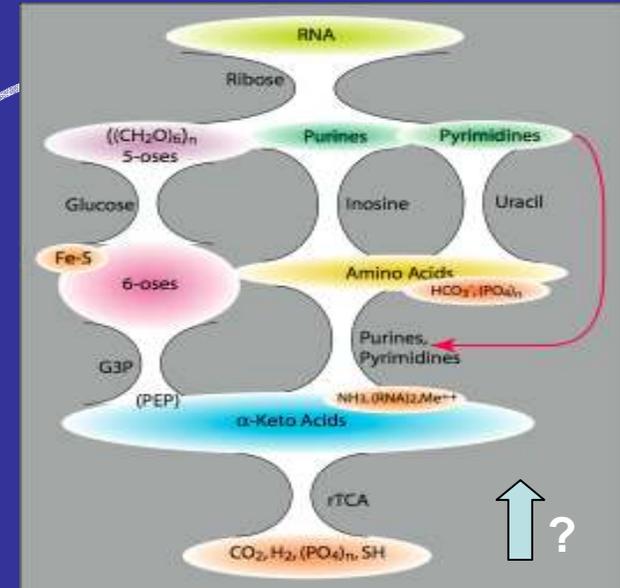
What are the indispensable requirements for life?



Membrane Encapsulation

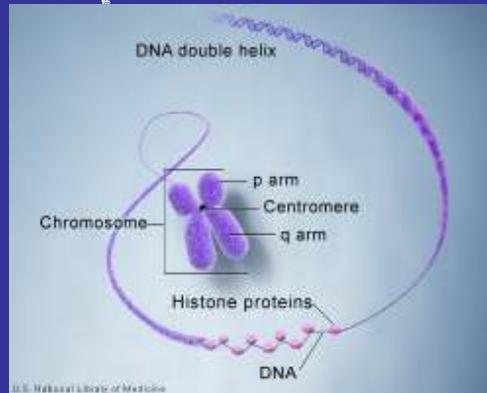
New Chemical Theories

Are There Alternative Routes to Life?



Eric Smith, SFI

?



Genome Stability

What are:

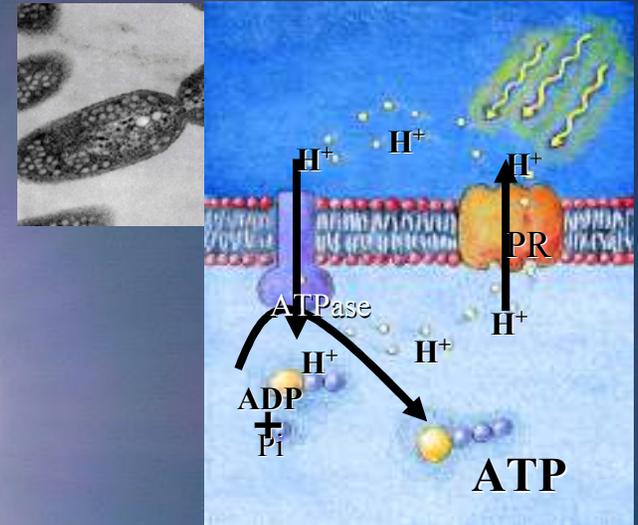
- The physical rules for cell membrane assembly?
- The minimum gene set required to sustain life?
- The fundamental requirements for genome stability?
- Chemical constraints?

Energy:

How can natural energy transduction systems inspire biology-based technologies capable of delivering clean, sustainable, and renewable energy?

Light-Driven Energy Transduction

Rhodobacter sphaeroides

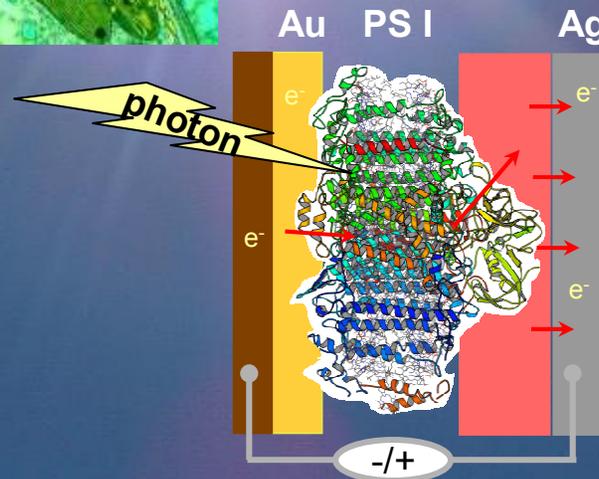


Chloroplasts



Proteorhodopsins
Edward Delong, MIT

Applied
Photosynthesis



Barry Bruce, U. TN

Adaptation:

Transformations and Transitions in the Story of Life



Extinction



Transformations



Adaptation and survival



Adaptation as a concept - what can we learn?

How have life forms adapted to planetary change?

How has the living world changed the planet?

Adaptation:

Life in a Time of Planetary Change



Earth's climate and life support systems are changing in novel and unexpected ways....

Adaptation:

How do living systems shape Earth's environment across scales of time, place and size?

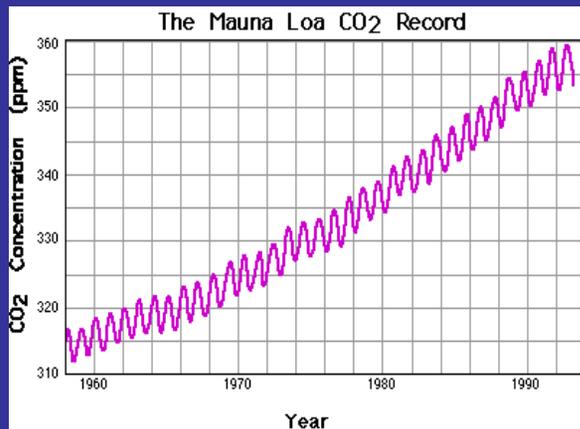


Figure 7.01 The record of CO₂ measured at Mauna Loa, Hawaii shows seasonal cycles — related to the activity of plants in the Northern Hemisphere — on top of an increasing trend to higher values. The record also shows a subtle increase in the seasonal amplitude over time.



↑
CH₄

↑
CO₂



Life in Transition

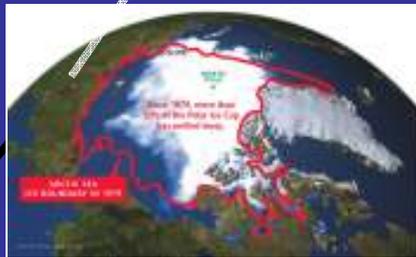
An absence of life?



Atmosphere
+
Geosphere
+
Biosphere



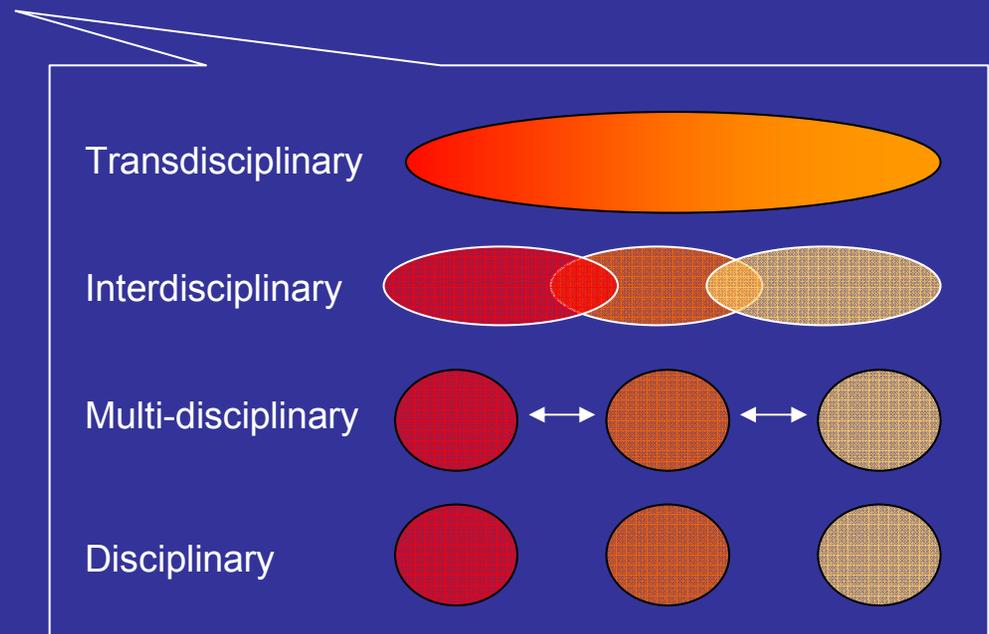
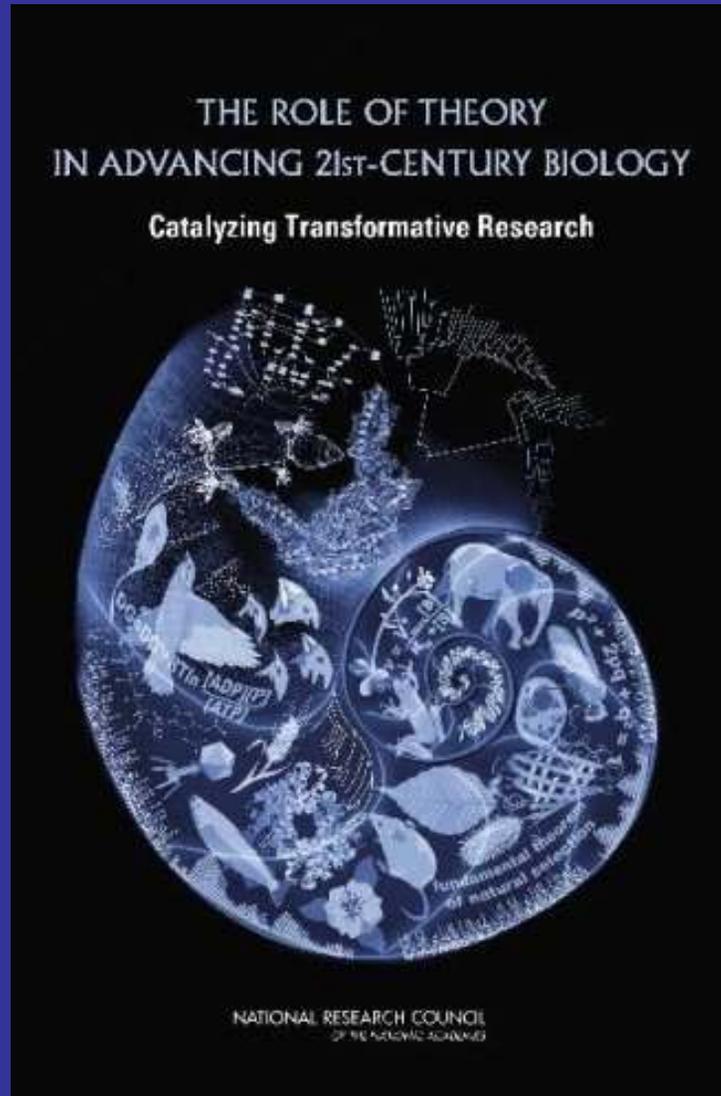
+
Anthroposphere



Integrating across drivers, responses, scales, and disciplines to reduce uncertainty about the future of life on Earth

Life Sciences in Transition

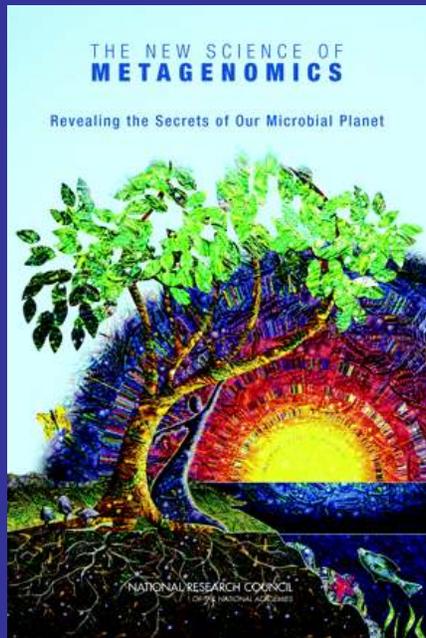
Challenges for 21st Century Biology



Life Sciences in Transition

Challenge: Connecting genomes to ecosystems

Community DNA



Ecophysiology



Ecosystem Metabolism



**EVOLVING
GENOMES**



**EVOLVING
POPULATIONS**



**CHANGING
ECOSYSTEMS**

Life Sciences in Transition

Challenge: Understanding Complexity



Hydra vulgaris

Sensing the Environment



Platynereis dumerilii

Movement



Eurycea lucifuga

Complex Nervous System

Life Sciences in Transition

Closing the Loop of Theory, Observation, Experimentation, and Technology

Animal model

- Primary source of data and behavioral phenomena

Mathematical model

- Describes hypothetical relationships between a selected subset of observations

Computational model

- Explores the logical consequences of the hypothetical descriptions (manipulate variables to mimic real world)

Physical model

- Explores the behavioral consequences of a hypothetical neural property operating in the animal's natural environment

D. E. Koditschek, ESE Department, University of Pennsylvania

Life Sciences in Transition

Challenge: Institutional change in biology education

Prepare a new generation of scientists to communicate science as a “precise, predictive, and reliable” way of knowing the world

**NSF-AAAS Vision and Change
Conference for Undergraduate
Biology Education
*July 2009***



NSF in Transition

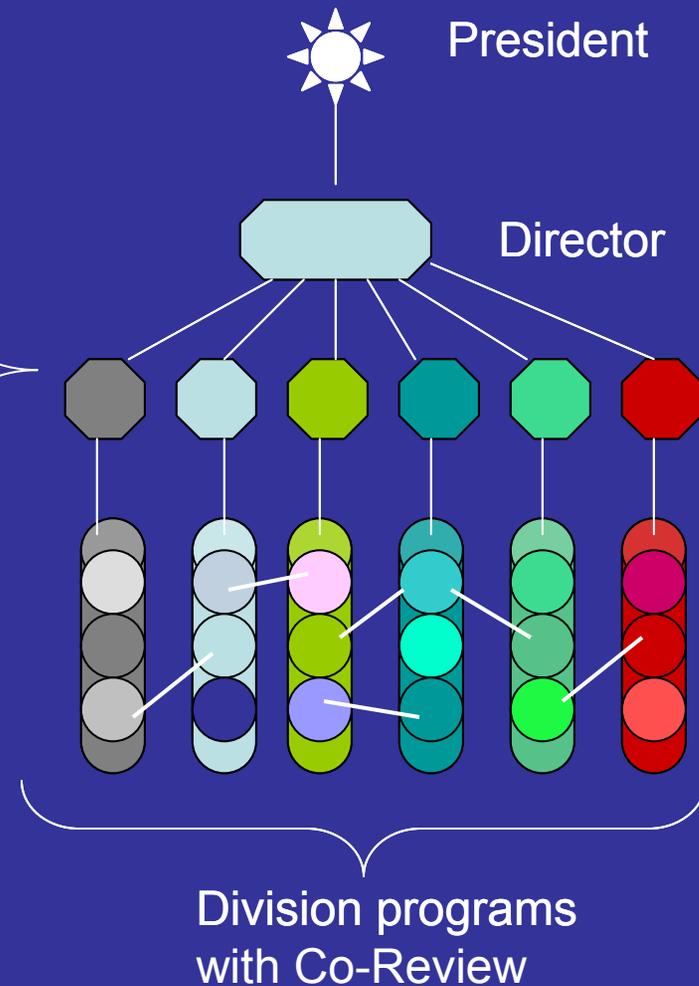
Encouraging Program Co-review

Sustaining Interdisciplinary Programs

Science and Engineering
Directorates Map to Traditional
Academic Disciplines

- Math and Physical Sciences
- Biological Sciences
- Geosciences
- Engineering
- Social and Behavioral Sciences
- Computer and Information Science

- Education and Human Resources



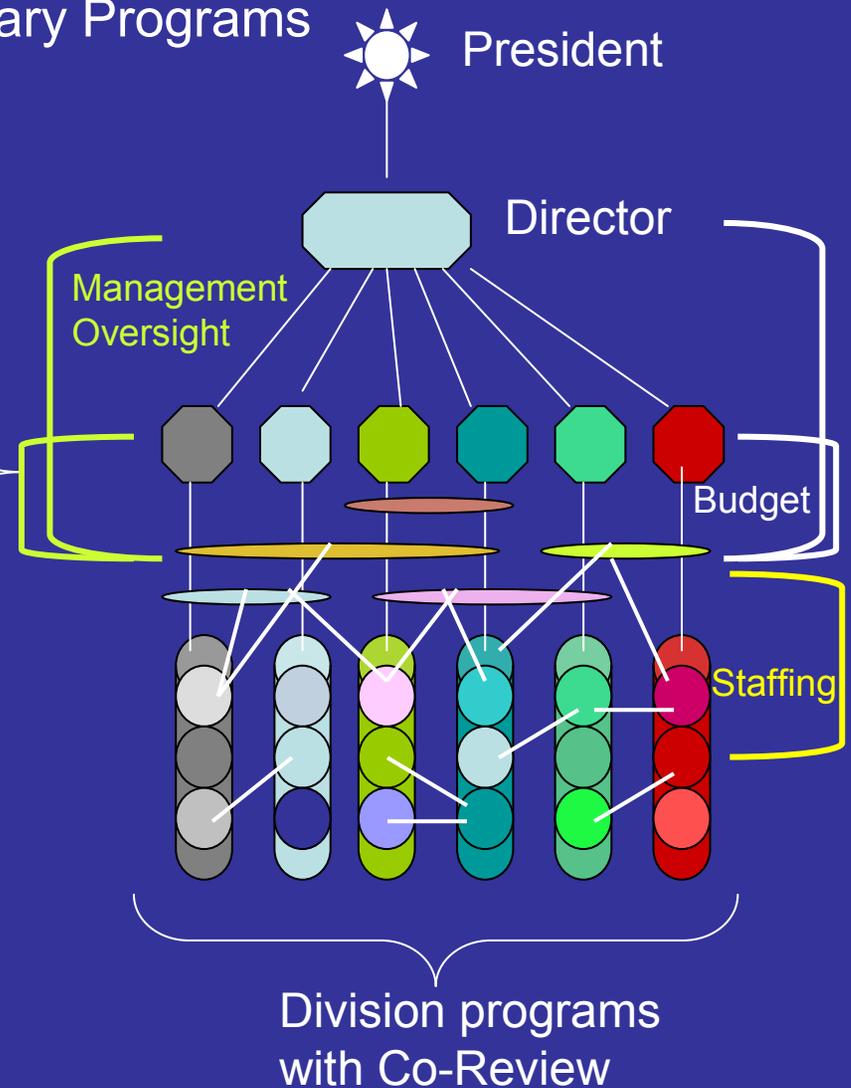
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Managing the Life Sciences in Transition

Reaching Beyond Traditional Disciplines

Connections at the intersection of the life and physical sciences

NATURE CHEMICAL BIOLOGY, Sept 2008

COMMENTARY

Chemical biology at the US National Science Foundation

Wilfredo Colon, Parag Chitnis, James P Collins, Janice Hicks, Tony Chan & Joanne S Tornow

Chemical biology continues to grow and blur the theoretical and empirical boundaries between chemistry and biology. Federal funding agencies, including the US National Science Foundation, will be essential to support the development of interdisciplinary research fields.

“In response to the growing number of proposals at the chemistry-biology interface...CHE and MCB created a shared program director position...”

Managing the Life Sciences in Transition

Experiments in Innovation

- **One Biology**
 - *Life in Transition DCL : origins, energy, adaptation*
- **BIO-GEO Collaboratory in Integrated Global Systems Science**
 - *Emerging Topics in Biogeochemistry DCL*
 - *Multiscale Modeling DCL*
- **“Sandpit”** real-time interactive peer review
 - Novel solutions to existing problems
 - New areas of inquiry – Synthetic Biology (BIO, MPS, ENG, SBE, EPSRC-UK)

Managing the Life Sciences in Transition

Multidisciplinary Programs

Dynamics of Coupled Natural and Human Systems

[BIO, GEO, SBE, & USFS]

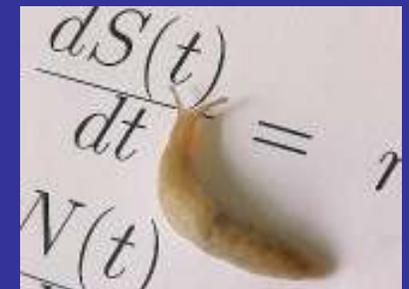


Ecology of Infectious Diseases

[BIO, GEO, SBE, & NIH]

Interdisciplinary Training for Undergraduates
in Biological and Mathematical Sciences

[BIO, EHR, & MPS]



Managing the Life Sciences in Transition

Engaging the Community

Building Capacity to
“Systems Biology”

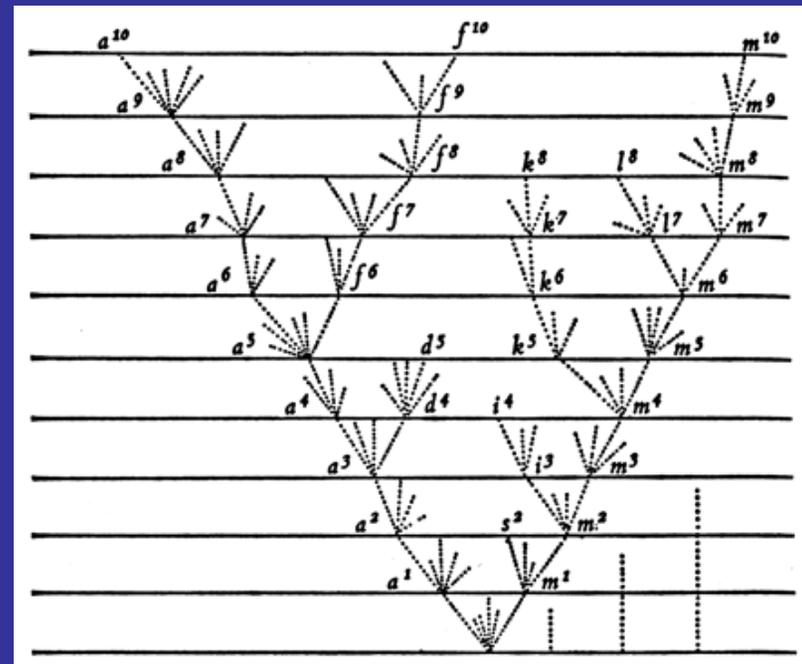
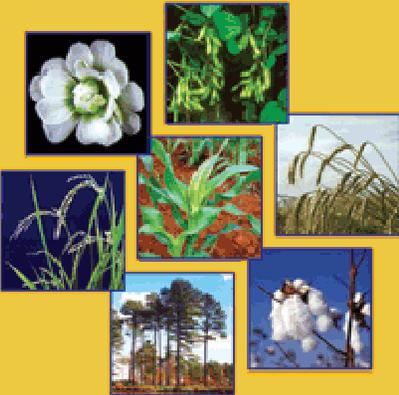
Advancing the Tree of Life to
“Ancestry of Life”



**National Plant
Genome Initiative:
2003 – 2008**

*National Science and Technology Council
Committee on Science
Interagency Working Group on Plant Genomes*

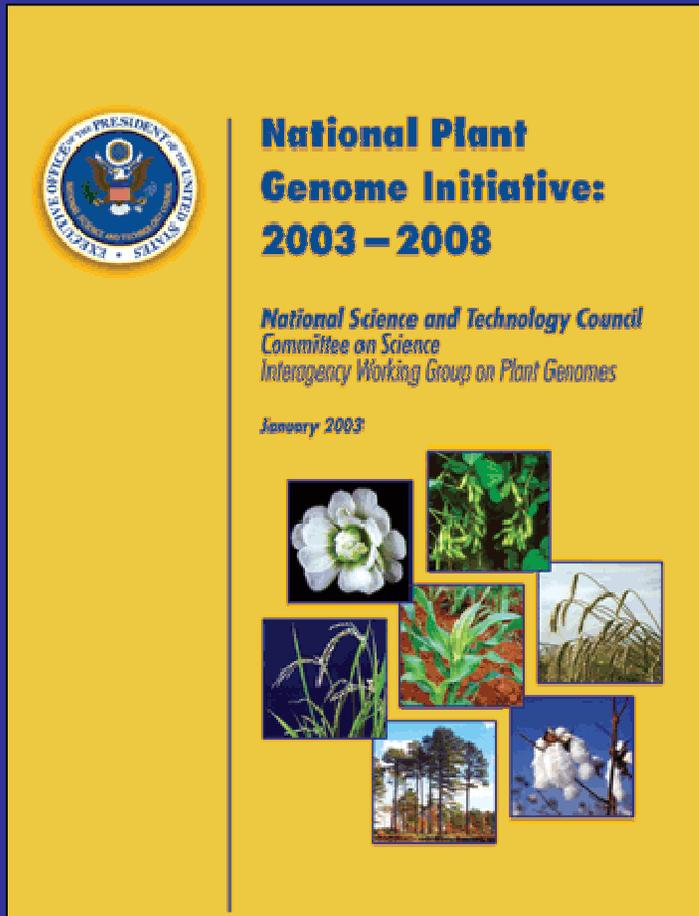
January 2003



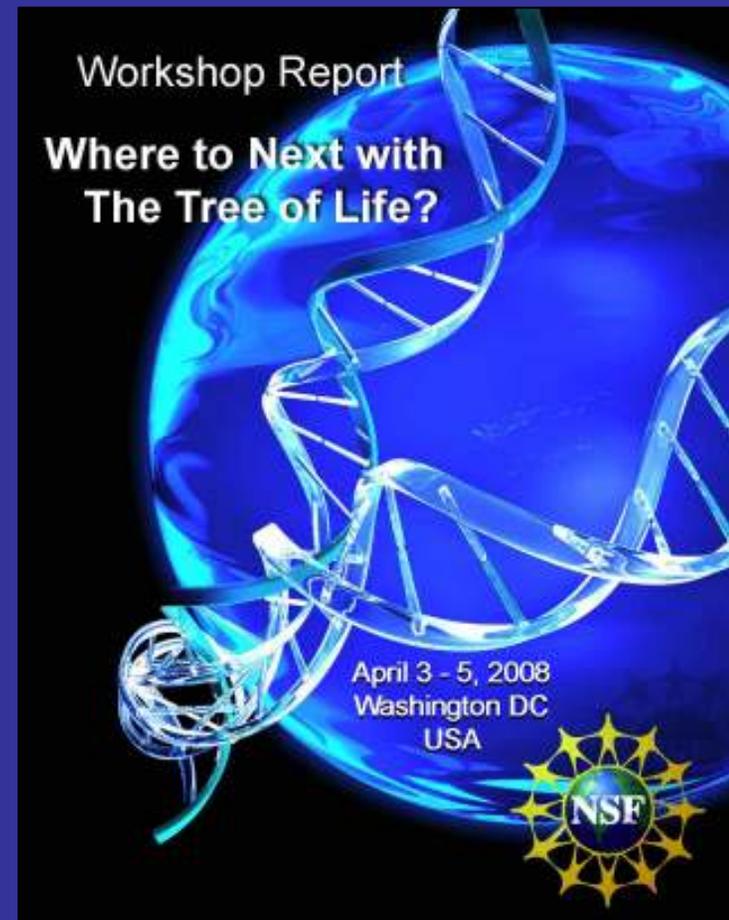
Managing the Life Sciences in Transition

Engaging the Community

Building Capacity to
“Systems Biology”

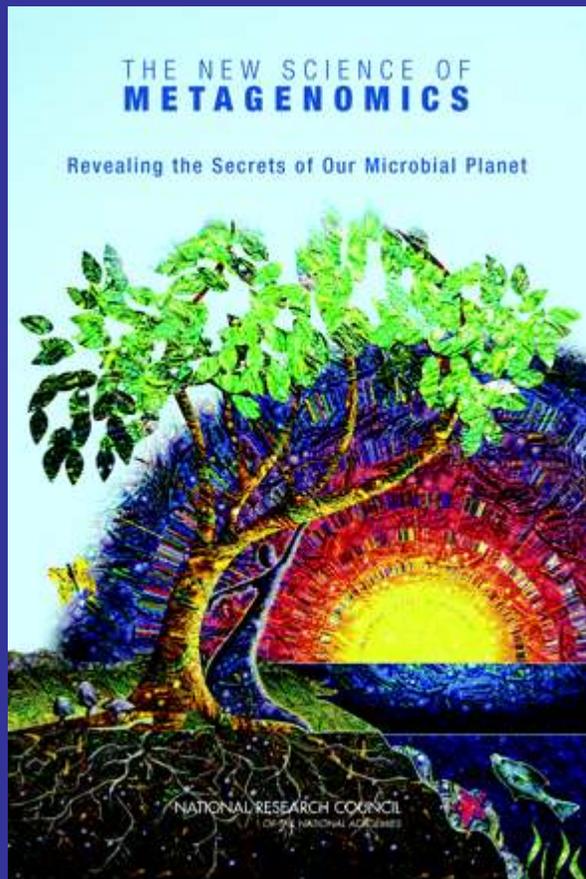


Advancing the Tree of Life to
“Ancestry of Life”

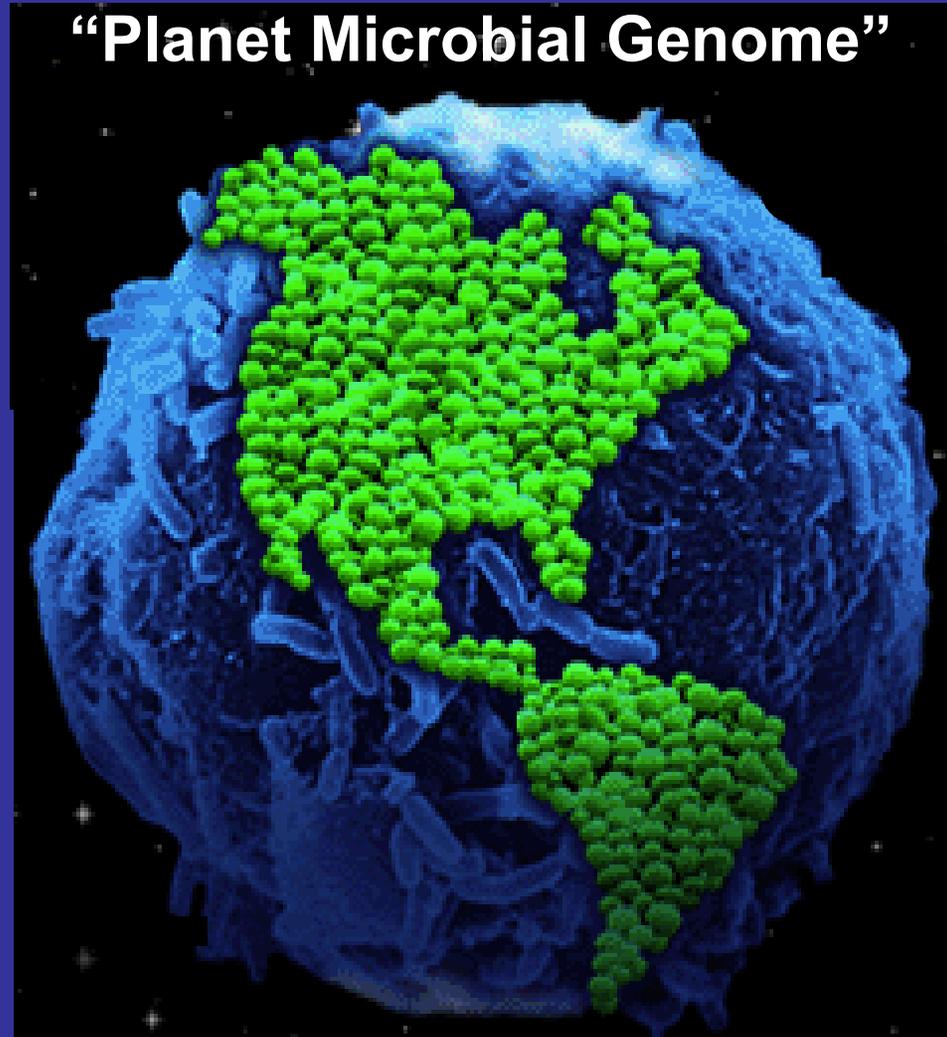


Managing the Life Sciences in Transition

New Tools and Approaches



“Planet Microbial Genome”



Managing the Life Science in Transition

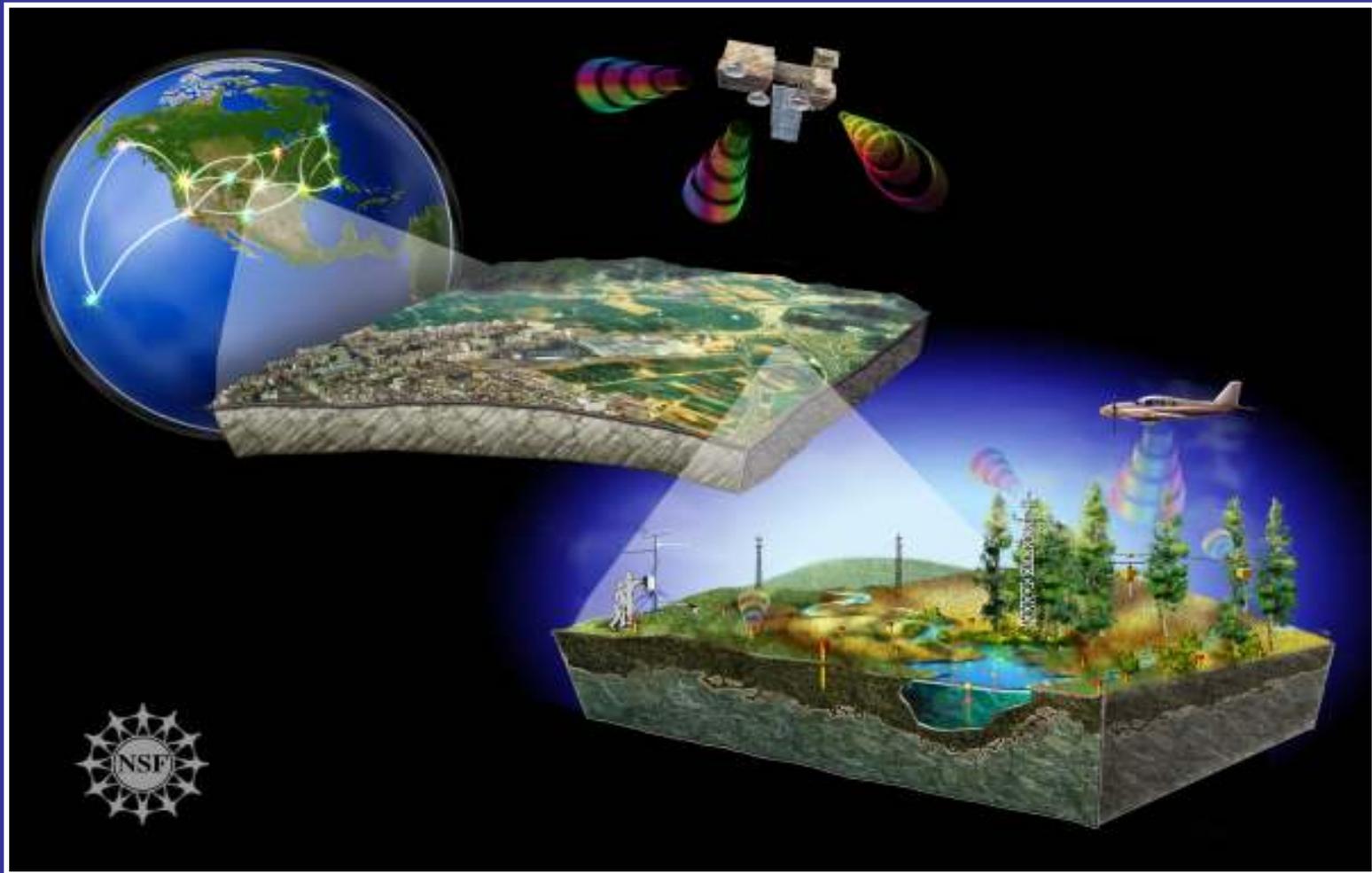
New Tools and Approaches

Cyber-Enabled Observatories

- **Hybrid operational and research platforms**
- **Long-term measurements**
- **Standardized infrastructure, procedures, quality control**
- **Free and open data access policy for near real time data**
- **Decision support tools**

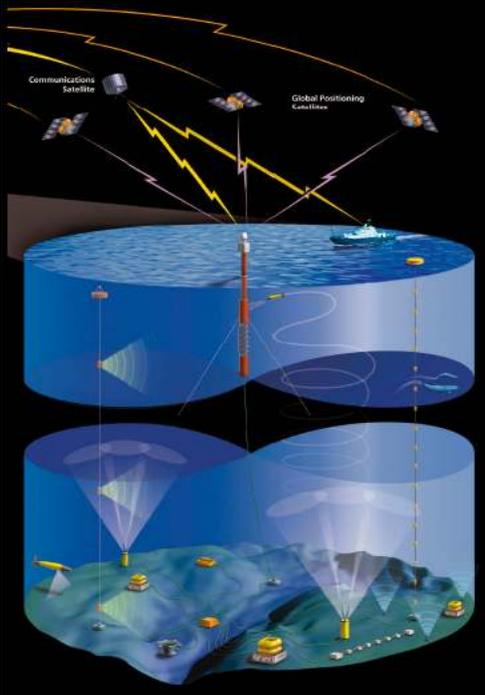
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New Tools and Approaches

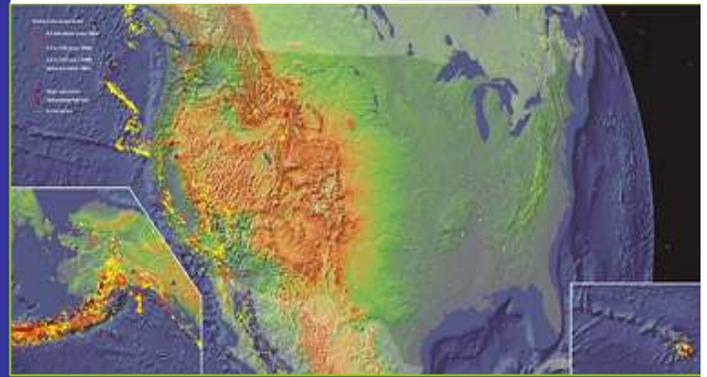


National Ecological Observatory Network (NEON)

ORION
*Ocean Research
 Interactive
 Observatory
 Networks*

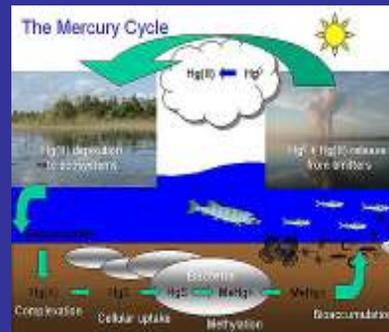


neon



New Horizons in Earth Observation

LTER



Managing the Life Sciences in Transition

Changing the “Culture”

- **The Academy:**
 - Value research that is discovery-based as well as research with a strong theoretical/conceptual basis
 - Reward “team driven” as well as individual research achievement
- **Research Community:**
 - Adopt open source information and rapid posting of new data
 - Develop and adopt new assessment technologies



Where discoveries begin